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Hearing loss in the aviation environment has been attributed to a variety of factors ranging from aircraft noise exposure to the aging process. Consequently, this study was conducted to determine the relative contribution of age, total flight hours, type of aircraft, and use of hearing protection to hearing loss in U.S. Army aviators. Information from a survey of the aviators in an aviation brigade was combined with audiometric records to create the data file. The final study group, 83% of the unit aviators, was evaluated for hearing loss using two criteria: 1) existing U.S. Army standards, and 2) four empirical categories of significant threshold shift. Data analysis suggests that hearing loss is primarily a function of noise exposure as measured by total flight hours. Age was found to be a less significant factor; aircraft type had no significant effect. The results indicate that combination hearing protection appears to significantly lower the risk of hearing loss.

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22a. NAME OF RESPONSIBLE INDIVIDUAL Daniel T. Fitzpatrick, Captain USA, MC	22b. TELEPHONE (Include Area Code) (512)536-2844; 22c. OFFICE SYMBOL USAFSAM/EDK

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An Analysis of Noise-Induced Hearing Loss in Army Helicopter Pilots

91-11023

DANIEL T. FITZPATRICK, D.O., M.P.H.

School of Public Health, University of Hawaii-Manoa, and Flight Surgeons Office, Schofield Barracks, Hawaii

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Hearing loss in the aviation environment has been attributed to a variety of factors ranging from aircraft noise exposure to the aging process. Consequently, this study was conducted to determine the relative contribution of age, total flight hours, type of aircraft, and use of hearing protection to hearing loss in U.S. Army aviators. Information from a survey of the aviators in an aviation brigade was combined with audiometric records to create the data file. The final study group, 83% of the unit aviators, was evaluated for hearing loss using two criteria: 1) existing U.S. army standards, and 2) four empirical categories of significant threshold shift. Data analysis suggests that hearing loss is primarily a function of noise exposure as measured by total flight hours. Age was found to be a less significant factor; aircraft type had no significant effect. The results indicate that combination hearing protection appears to significantly lower the risk of hearing loss.

THE PROBLEMS associated with noise in the aviation environment have existed since the onset of powered flight. Aircraft noise exposure is considered to be one of the major factors causing permanent loss of hearing among today's military aircrew members (2,7,8,10). The unique maneuvering capability which makes the helicopter so valuable has unique acoustic problems associated with it. The noise produced by the multitude of Army aircraft varies, but some general findings are associated with all of them. Usually, noise levels are most intense at the lower frequencies (300 Hz or less); in their overall operation, all Army rotary-wing aircraft exceed levels of 100 dBa (1). The noise sources that make a significant contribution to these intense noise levels include the main transmission, engines, rotors and the sympathetic vibrations of fuselage structures (4,9).

A recent study (11) has implicated the biological process of aging (presbycusis) as the major factor associated with hearing loss in this population. With conflicting results in the literature, this study was conducted to determine which factors are specifically relevant to U.S. Army helicopter pilots. The relative contributions of age, total flight hours, type of aircraft, and type of hearing protection to observed changes in hearing thresholds were evaluated.

METHODS

Due to current Army reorganization under the "Light Division" concept, an aviation brigade was selected as the most appropriate study unit. Pilots from the 25th Aviation Brigade at Schofield Barracks, Hawaii, were chosen as the study population. Based on standard demographic characteristics, there is no reason to believe that this group is atypical of its peers Army-wide.

A written survey of all 215 assigned pilots was undertaken; the survey was completed by 98%, or 211 pilots. Information obtained was age, total flying hours, type of aircraft flown, and type of hearing protection used. To maintain consistency, the same individual conducted the survey over a 6-week period. Total flying hours and years of flying were estimated to the date of the survey.

Aircraft type was analyzed; the primary aircraft was determined to be the one in which the pilot flew at least 80% of his total hours. To validate the relative accuracy of reported flying hours, the flight records of 20% of the study population by age groups were reviewed to confirm the total flying hours accumulated. The correlation between surveyed and actual total flight hours ranged from 0.98 to 1.00.

All medical records were screened to obtain detailed information for both the initial reference and most current audiograms. The records were also reviewed for evidence of hearing loss due to causes other than noise

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Address reprint requests to CPT Daniel T. Fitzpatrick, who is a U.S. Army flight surgeon currently completing an aerospace medicine residency at USAF School of Aerospace Medicine (USAFSAM/EDK), Brooks AFB, TX 78235-5301.

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exposure. This review resulted in the elimination of 29 subjects due to hearing loss prior to flying or to otologic problems other than noise exposure, and 4 more for incomplete audiology records. The audiometric tests, performed annually on Army aviators, consisted of air conduction hearing tests in the frequency range of 500–6,000 Hz. Generally, audiometric examinations are performed in acoustically-treated rooms using audiometers calibrated to the International Standards Organization (ISO 1964) or the American National Standards Institute (ANSI S3.6-1969).

The final study group, totaling 178, had an average age of 31.7 years with an average of 1,484 total flying hours. However, this distribution is slightly skewed to the left with respect to age and total flight hours. The majority of pilots are under age 30 and have flown less than 1,000 hours in a variety of aircraft.

Hearing Classification and values of significant threshold shift were defined according to the following criteria:

1) Classification of hearing threshold levels by United States Army Standards (12): unaided hearing sensitivity is classified as H-1, H-2, H-3. H-1 refers to an audiometric average of 500, 1,000, and 2,000 Hz that cannot exceed 25 dB with no individual level greater than 30 dB. Threshold at 4,000 Hz cannot exceed 45 dB. H-2 requires, for both ears, that an audiometric average of 500, 1,000, and 2,000 Hz cannot exceed 30 dB with no individual frequency level greater than 35 dB. Threshold at 4,000 Hz cannot exceed 55 dB. Alternatively, for the better ear the threshold cannot exceed 30 dB at 500 Hz, 25 dB at 1,000 Hz, and 2,000 Hz, and 35 dB at 4,000 Hz; the worse ear can have any configuration. H-3 includes levels exceeding H-2, and speech reception threshold cannot exceed 30 dB HL in the better ear with the use of a hearing aid.
2) Classification by frequency groups using significant threshold shift (STS). Threshold shift was calculated by subtracting the hearing threshold level at each frequency of a preflight reference audiogram, from the level appearing on a current audiogram. A threshold shift of 25 dB was selected as a fulcrum since the American Academy of Otolaryngology-Head and Neck Surgery has used an average absolute hearing level of 25 dB at 500, 1,000, and 2,000 Hz as the threshold for impairment (5). The following categories were established: Class 1 refers to a decibel shift of less than 25 dB for all frequencies. Class 2 refers to a decibel shift of 25 dB or more for any frequency in the 500–2,000 Hz range, the speech frequencies. Class 3 refers to a decibel shift of 25 dB of more involving both speech and high frequencies (3,000–6,000 Hz). Class 4 refers to a decibel shift of 25 dB of more at 4,000 or 6,000 Hz, the high frequencies.

Computation and statistical analyses were performed at several levels. In univariate analysis hearing levels and significant threshold shifts were analyzed in relation to age, flight hours, hearing protection, and aircraft type. Multivariate analysis used the multiple regression stepwise technique.

RESULTS

Tables I and II demonstrate the various degrees of hearing loss. As can be seen from Table I, using U.S. Army standards 8.4% of the population suffered from hearing loss. However, using the more sensitive classification of significant threshold shift as presented in Table II, 29.7% of the population demonstrated a loss of hearing; high frequency loss was the dominant category. There appears to be no association between hearing loss and aircraft type; however, strong relationships exist for the other variables. A Chi square analysis using STS criteria indicates the following: there is a clear progression of hearing loss by age group ($p < 0.001$); dependency on flight hours is also seen with a four-fold increase in the percent of pilots with a threshold shift from under 1,000 to 4,000 hours ($p < 0.001$); and there is a clear dependency to hearing protection ($p < 0.01$). Similar results were obtained using U.S. Army standards.

Statistical analysis shows a highly significant relationship between age and flight hours ($p < 0.001$). To determine if hearing loss is truly a function of noise exposure, as indicated by total flight hours, the data were reanalyzed by adjusting for age. The Pearson's correlation revealed a persistent and significant association ($p < 0.05$) for total flight hours.

Table III presents the average hearing threshold lev-

TABLE I. DISTRIBUTION OF HEARING LOSS (%) BY ARMY CRITERIA.

Criteria	H-1	H-2 + 3	Freq.
1. Age (years)			
≤29	100.0	—	75
30–34	97.7	2.3	44
35–39	76.7	23.3*	43
≥40	75.0	25.0	16
2. Total Flight Hours (h)			
≤999	99.0	1.0	97
1,000–1,999	86.2	13.8	29
2,000–2,999	84.2	15.8	19
3,000–3,999	75.0	25.0*	16
≥4,000	82.4	17.6*	17
3. Hearing Protection			
Helmet Only	86.2	13.8*	87
Mixed[a]	95.0	5.0	20
Helmet + Earplugs	97.2	2.8	71
4. Primary Aircraft			
AH-1	100.0	—	7
OH-58	100.0	—	21
UH-1	94.9	5.1	59
UH-1/UH-60	92.9	7.1*	14
UH-1/AH-1	89.5	10.5	19
UH-1/OH-58	88.0	12.0	25
Other[b]	90.0	10.0	10
3 Aircraft[c]	78.3	21.7*	23
Total	91.6	8.4	178

* Indicates location of 2 Class H-3 subjects.
a = Indicates intermittent use of earplugs.
b = Types of rotary-wing aircraft other than listed.
c = 3 or more rotary wing aircraft.

TABLE II. DISTRIBUTION OF HEARING LOSS (%) BY STS CRITERIA.

Criteria	Class 1 (No Loss)	Class 2 (0.5K–2K)	Class 3 (3K–6K)	Class 4 (4K–6K)	Freq.
1. Age (years)					
≤29	92.0	—	—	8.0	75
30–34	72.7	—	4.5	22.7	44
35–39	46.5	4.7	9.3	39.5	43
≥40	25.0	—	25.0	50.0	16
2. Total Flight Hours (h)					
≤999	86.6	—	1.0	12.4	97
1,000–1,999	51.7	3.4	3.4	41.4	29
2,000–2,999	63.2	5.3	10.5	21.1	19
3,000–3,999	50.0	—	12.5	37.5	16
≥4,000	35.3	—	23.5	41.2	17
3. Hearing Protection					
Helmet Only	62.1	1.1	6.9	29.9	87
Mixed[a]	60.0	5.0	—	35.0	20
Helmet + Earplugs	83.1	—	5.6	11.3	71
4. Primary Aircraft					
AH-1	71.4	—	—	28.6	7
OH-58	85.7	4.8	—	9.5	21
UH-1	84.7	1.7	1.7	11.9	59
UH-1/UH-60	64.3	—	—	35.7	14
UH-1/AH-1	57.9	—	—	42.1	19
UH-1/OH-58	72.0	—	16.0	12.0	25
Other[b]	40.0	—	10.0	50.0	10
3 Aircraft[c]	43.5	—	17.4	39.1	23
Total	70.2	1.1	5.6	23.0	178

a = Indicates intermittent use of earplugs.
b = Types of rotary-wing aircraft other than listed.
c = 3 or more rotary-wing aircraft.

els for the two main study parameters (left ear). A substantial hearing loss is noted for the higher frequencies (4,000–6,000 Hz); it becomes progressively worse as age and flight hours increase. One notable exception is the lower threshold levels seen in the 2,000–2,999 flight hour group. These same trends were also observed in the right ear, however threshold levels were consistently poorer in the left.

Table IV shows the relationship of age to flight hours in the study population. The U.S. Public Health Survey of 1965 (6) reflects an increase in hearing loss (3,000–6,000 Hz) with aging for the general population. With none of the over-40 pilots in the 2,000–2,999 flight hour range, the improved threshold levels noted in this group may be attributed to this somewhat skewed age distribution.

When comparing the two sets of criteria, the significant threshold shift criteria revealed impaired hearing in younger pilots with fewer flying hours than did the Army hearing classification. Many of those with STS later progress to meet U.S. Army criteria. A detailed breakdown of hearing loss by frequency (Table V) shows 6,000 Hz the most commonly occurring frequency using STS criteria, while hearing loss by U.S. Army standards occurs most often at 4,000 Hz. The same findings were also noted in the right ear.

Analysis by Pearson correlation (Table VI) again shows the strong relationship of both age and total flight

TABLE III. AVERAGE HEARING THRESHOLD (dB) FOR STUDY PARAMETERS (LEFT EAR).*

Frequency (Hz)	500	1,000	2,000	3,000	4,000	6,000
Age (years)						
≤29	5.6	4.3	4.4	5.5	6.5	15.4
30–34	7.1	5.6	4.3	8.3	13.5	17.5
35–39	7.4	6.3	7.9	14.7	18.5	29.7
≥40	7.5	7.2	6.3	15.3	24.7	25.6
Total Flight Hours (h)						
≤999	6.1	4.4	4.1	6.6	8.5	16.0
1,000–1,999	6.9	6.7	6.9	9.5	17.1	27.2
2,000–2,999	5.3	4.5	4.5	11.1	11.1	17.1
3,000–3,999	5.9	7.2	8.1	13.8	22.5	26.6
≥4,000	10.6	7.7	8.8	17.9	22.7	30.3

* Based on most current audiogram.

TABLE IV. FREQUENCY DISTRIBUTION OF AGE BY FLIGHT HOURS.

	Age (years)				
Total Flight Hours (h)	≤29	30–34	35–39	≥40	Total
≤999	65	27	4	1	97
1,000–1,999	6	11	8	4	29
2,000–2,999	3	4	12	—	19
3,000–3,999	1	2	9	4	16
≥4,000	—	—	10	7	17
Total	75	44	43	16	178

hours to hearing loss. In addition, multivariate analysis by stepwise regression shows the significant relationship of age and flight hours to hearing loss, especially in the high frequency range. Hearing protection produced only a minimum association; the type of aircraft flown was shown to have no effect on hearing loss.

DISCUSSION

Previous studies evaluating the effects of noise on hearing in the aviation environment have resulted in a diversity of findings. These range from a positive correlation of noise exposure to hearing loss (2,7,10) to no clear dependency on aircraft noise (3) to the process of aging as the primary factor (11). These different findings may be due to several reasons, including the fact that each of these studies evaluated noise exposure to a variety of aircraft with diverse characteristics. The size of the study population and evaluation techniques also varied greatly.

TABLE V. DISTRIBUTION OF HEARING LOSS (%) FOR STUDY CRITERIA (LEFT EAR) BY FREQUENCY.

		Army Standards	
Freq. (Hz)	STS	(onset) 1	(current) 2
500	—	—	—
1,000	1.9	6.7	6.7
2,000	1.9	13.5	26.7
3,000	17.0	40.0	53.3
4,000	41.5	80.0	80.0
6,000	54.7	73.3	80.0

Percentage based on total population defined by each criteria.
1 Onset = based on first detected audiometric changes.
2 Current = based on most recent audiogram.

This study evaluated the effects of helicopter noise exposure on hearing in U.S. Army aviators in one brigade, with no indication that this population is atypical of other aviation units Army-wide. Hearing loss by STS criteria often occurred in younger pilots with fewer flight hours. As expected, hearing loss by U.S. Army standards occurred predominantly in a slightly older, more experienced group. The difference in the prevalence rates of the two criteria indicates that 21.4% of those considered to have acceptable hearing by U.S. Army standards have actually suffered a significant loss according to a reasonable threshold shift criterion. During the written survey, all pilots were asked if they had any history of hearing loss. Results indicate that 74% of those with a documented significant threshold shift were totally unaware of any hearing loss.

In addition to speech frequencies, the current U.S. Army classification standards consider only 4,000 Hz. With almost one-third of the study population experiencing threshold shifts above this level, and many of them progressing to a more significant hearing loss, monitoring these early changes could possibly prevent further progression by introducing corrective measures earlier. Lack of attention to hearing status until an individual fails to meet the required standards often results in irreversible damage.

The excessive noise levels encountered in Army aviation mandates hearing protection. Although the SPH-4 helmet provides acceptable noise attenuation, the study data indicate that the additional use of earplugs appears to significantly lower the risk of hearing loss. This im-

TABLE VI. PEARSON CORRELATION BETWEEN HEARING THRESHOLD TO AGE AND FLIGHT HOURS.

	Age		Flt. Hrs.	
Freq. (Hz)	(R) Ear	(L) Ear	(R) Ear	(L) Ear
500	.10	.16*	.05	.17*
1,000	.11	.18**	.04	.15*
2,000	.14*	.14*	.10	.16*
3,000	.30***	.34***	.25***	.32***
4,000	.49***	.41***	.31***	.33***
6,000	.44***	.33***	.34***	.28***

Correlations based on most current audiogram.
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.
n = 178 cases.

provement may be due to the reduction of "noise at the ear" due to the communication systems, and due to factors such as a loosely fitting helmet.

In conclusion, it appears that hearing loss in Army aviators is mainly a function of helicopter noise exposure, as measured by total flight hours. The effects of age, as documented in the general U.S. population, is also a contributing factor. The use of combination hearing protection plus early identification of significant threshold changes are important steps in reducing the prevalence of hearing loss in the Army aviation community.

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